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PRESENT AND FUTURE DEVELOPMENTS IN BULK STORAGE OF PRODUCE

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by F. N. Wright

Introduction

1. At present a great deal of produce is stored in bags although, as has already occurred with many non-food materials, attention is being given to storage in bulk. Before discussing developments in bulk storage it would be useful to outline the advantages and disadvantages of bag and bulk storage.

2. The advantages of bag storage include convenience of handling by manual labour, ease of transportation by different kinds of haulage, suitability for the storage of small quantities of several separate types of produce in one building and a low capital outlay for premises. Bag storage enables simple methods of checking the quality of produce to be used and provides for a resale value of the container (the bag). Disadvantages are that bags require more storage space, they allow uptake of moisture, infestation by insects, fouling by rodents and they are costly and require the employment of a labour force which is becoming increasingly expensive to employ.

3. The advantages of bulk storage are that it requires the minimum of space, enables large quantities of produce to be handled quickly, efficiently, and with the minimum amount of labour, and eliminates the cost of bags. In addition, access by rodents can be eliminated and better protection can be given against reinfestation by insects. The main disadvantage is the relatively high capital cost of the container and ancillary equipment. Other disadvantages are that bulk storage is less easy to inspect and 'hot spots' due to breeding of insects can develop more easily.

4. Irrespective of the storage method used, in order to store produce without deterioration, certain requirements have to be fulfilled. Although grain is living and respiring, producing carbon dioxide, water and heat, if it is dry and uninfested the rate of production of these waste products is extremely low and of no significance. If grain is damp, aerobic moulds, with their very rapid rate of respiration, produce large amounts of carbon dioxide water and heat. Even if relatively dry, grain can be attacked by insects which also respire rapidly and produce large amounts of carbon dioxide, water and heat. Such damage can be prevented by drying to prevent mould growth and cooling to retard insect development. Drying is economically possible even under tropical conditions but cooling is not. In tropical countries drying is usually by means of the sun, elsewhere it is often supplemented by artificial means, being carried out by applying small volumes of very hot air or large volumes of warm air.

5. Since there is a relationship between the moisture content of a commodity and the relative humidity of the air with which it is in contact, due account must be taken of this when deciding, in a particular climate, the best form of storage to be used and the level of moisture content at which a commodity can be taken into store. Commodities vary in their equilibrium relationships with the moisture in the air and safe storage moisture contents may be low such as 6% for groundnuts or high such as 14% for paddy. These are the values of moisture content for these commodities in equilibrium with 70% relative humidity. It is only if the relative humidity of the air in contact with the produce rises above this level that moulds will be able to grow on the produce. At this level, insects can develop freely but their rate of development is progressively prolonged the drier the produce.

6. Temperature of the stored produce is important; in general terms the safe moisture contents in temperate climates are higher than those in tropical climates. Thus while a cereal grain can be stored reasonably safely at a moisture content of 14.5% in the United Kingdom, in the tropics a figure of 13% is the more usual limit.

Detection of deterioration

7. In the past the practice has been established to put produce into storage and leave it until it is required. It is important to make regular checks, e.g. weekly or fortnightly, during the storage period to ensure early detection of deterioration such as translocation of moisture and development of fungi or insects. The beginnings of deterioration problems can be inferred from certain data.

Moisture Content

8. If a product is dry, it will not be attacked by moulds or readily attacked by insects. Determination of moisture content is therefore important and should be carried out as a routine measure in all storage installations. Various rapid methods are available, and although these are usually less accurate than the slower "standard" methods, they allow more determinations to be made in a given time, so that a bulk may be more widely sampled.

Temperature

9. The production of heat by living insects has already been mentioned, thus measurement of the temperature of grain is often a good index of its condition. The presence of insects in dry grain, i.e. between moisture contents of between 11 and 15% giving rise to a temperature rise not exceeding 52°C. is known as dry grain heating. Temperature gradients may thus arise and the subsequent movement of moisture produces areas of higher moisture content. Heating of grain can also be caused by 'damp grain heating' which occurs in grain of moisture content exceeding 15% which can develop in damp grain even in the absence of insects; usually the moisture content is 17 or 18% and the maximum temperature is likely to exceed 42°C; usually a temperature of 50 - 52°C is reached (1). This kind of heating is due to the presence of moulds; a frequent sign of this kind of deterioration is caking of the grain, e.g. under metal manholes where a drop in temperature can lead to condensation.

(1) Oxley, T.A., The scientific principles of grain storage. Northern Publishing Co. Ltd., Liverpool (1948).

In bulk storage it is important to measure temperatures of the bulk, particularly, change in temperature. This can most conveniently be done by a permanent temperature measuring or recording installation. Sometimes, however, it is more practical to insert temporary devices, often using thermocouples or thermistors, in regions where deterioration is suspected.

Carbon dioxide

10. The production of carbon dioxide by insects can also be used as a means of detecting their presence by the so-called carbon dioxide method (2). This depends on the fact that in a sample of grain the insects present, although representing only a fraction of the weight of the sample, produce very much more carbon dioxide than the grain itself. If a sample of grain is incubated for 24 hours at 25°C and the concentration of carbon dioxide in it estimated by a gasometric method, so-called carbon dioxide figures can be produced which are a measure of the amount of insect infestation present. Thus a figure of 1% carbon dioxide would indicate that a heavy insect infestation was present. This method is most useful in detecting 'hidden' infestation i.e. where insects are present inside the grains and not seen by the human eye.

Examination for insects

11. By far the most common method of assessing insect infestations is the actual finding of insects on the bulk, or at the outlet spout or in a sample. Surface infestations can be detected by examination of the grain surface, walls and ceilings of the bin. Apart from seeing any live insects, evidence of their presence may be gained from such signs as webbing produced by the larvae of moths. Surface examination should be supplemented wherever possible by the taking of samples deeper in the grain; for this purpose deep sampling spears (tubes with compartments) may be used. It should be borne in mind that the detection of living insects in a bulk of grain may be very difficult if there is a very light infestation, and also that the sample examined represents a very small fraction of the total bulk. Infestations can therefore be missed. It is advisable not to rely on any one method for the detection of insects but to use a combination of the methods indicated.

Traditional storage structures

12. The simplest type of bulk storage is in a heap on the floor of a building. This is called flat storage because the length or width of the pile is greater than its height; it is to be contrasted with upright storage usually associated with bins where the height generally exceeds the length or breadth of the bulk. With flat storage, normally the produce is heaped in such a way as to prevent pressure on the walls, otherwise reinforcing of the walls is necessary to withstand the lateral pressures of the bulk; bulkheads of bagged grain or wooden supports are frequently used to limit the area of a pile of grain. This method of storing grain has the advantage of cheapness and confines damage by rodents to the surface, but it presents difficulties in controlling insect infestation.

13. Generally, bulk storage is in bins which may be sited within a building or

(2) Howe, R.W. and Oxley, T.A. The use of carbon dioxide production as a measure of infestation of grain by insects. Bull. Entomol. Res., 35, 11-22 (1944).

independent of a building; in the former case they are frequently open-topped and in the latter they are roofed. In cross section, bins are usually circular, square, rectangular or hexagonal. For any given capacity and strength the cylindrical form utilises less building material and is thus the cheapest, but requires additional floor space compared with square or rectangular bins of the same height and capacity; where a double row of bins is erected, however, use can be made of the space between bins by utilising these as inter-space bins. Square or rectangular etc. bins may be designed to fit more easily into an existing building than circular ones and can also be used to form the outside wall of a building.

14. A variety of materials is available for the construction of bins. For very large installations (50 tons or more) reinforced concrete or steel are likely to be used, but for smaller bins (less than 50 tons) concrete blocks, bricks, timber, plywood, aluminium and galvanised steel may be used. The choice of material is largely influenced by the availability of local building materials and the skill of local staff for erection; if cement is available locally precast concrete blocks may be used for bins which can be erected, under supervision, by unskilled labour. Where bins have to be imported there is a choice of prefabricated metal or plywood silos which are shipped in sections and can be easily bolted together on suitably prepared foundations which must be waterproof to prevent liquid water and rising water vapour from penetrating into the commodity stored.

15. In designing bins it is necessary to consider the internal pressures which will be attained. Grain behaves somewhat like a liquid exerting both downward and lateral pressure; thus the weight of the grain is supported by both the floor and the walls. This lateral pressure, which is usually about one third to one half of the vertical pressure, increases very little once a depth of about $2\frac{1}{2}$ - 3 times the diameter of the bin has been reached, and it is because of this fact that tall bins can be built. Lateral pressure is important when determining the strength requirements of the bin walls.

16. A dual role is fulfilled by ventilated bins in which grain is not only stored but dried. In these bins heated air is blown by a fan through ducting underneath the bins which have a porous floor of some kind allowing the heated air to pass up through the produce. Another type is the radially ventilated bin which is constructed of perforated or expanded metal with a central aerating duct; this type is rarely used for storage, serving only as a drier from which the dried grain is removed to more conventional bins.

17. The individual grains of most cereals are very robust and are not affected by the great pressures occurring in tall silos and are relatively undamaged by the handling processes in and out of bins. Other commodities however are more sensitive to pressure and friction and, are liable to sustain damage, particularly during filling and emptying. With such commodities as groundnuts, soya beans (3) and cocoa beans special attention has to be paid to mechanical handling equipment and as much use as possible made of belt-conveyors and, a slow moving chain and bucket elevator used for elevation; in addition specially designed silos may be required. Cocoa beans, for instance, are relatively brittle and cannot be allowed to fall from great heights onto the floors of bins thus special devices have to be incorporated in the silos to check the free fall of cocoa beans.

(3) Holman, L.E., Handling and storage of soybeans, in Markley, K.S. (Ed.) Soybeans and soybean products, Vol. I., Interscience Publishers, Inc., New York, (1950).

These may take the form of a series of baffles which only allow beans to fall about a foot at a time; even so this repeated buffeting could damage beans in a very deep bin; thus the use of baffles should be limited to bins not more than about 45 feet deep. For deeper bins some form of spiral slide is required. Special devices may also have to be incorporated to reduce friction during unloading (4).

18. Apart from strength considerations, it is most essential that the structure be waterproof; particular attention must be paid to making foundations waterproof so that moisture is not transmitted through the plinth and into the grain. All bins should be rodent-proof and if possible they should also be insect-proof. Since the latter is very difficult to achieve, an essential feature, not easily attainable with many types of silos, is that bins should be sufficiently gastight to enable successful fumigation to be carried out. Thus ordinary bolted construction is not desirable since gas can leak out through the bolt holes. The internal walls of bins should be smooth so as to prevent harbourage of residues and insects.

New types of storage structures

19. The erection of permanent bulk storage systems needs a large capital outlay and generally once built, the bins cannot be moved, although plywood and metal bins of small capacity can, if necessary, be dismantled and erected elsewhere. There are occasions however when in some years excess harvests are produced and existing storage facilities are inadequate. In such circumstances there is a need for quickly erected portable storage structures; this need may be fulfilled by various plastic structures (5).

20. One plastic structure in which considerable interest is being currently shown for bag storage is the 'airhouse'. This consists of a flexible plastic envelope made from a base fabric of synthetic material coated with a plastic; the shape of the envelope is maintained by blowing air into it, using electrically operated or petrol-powered fans. Such a building suitably shaped to the angle of repose of grain could be used to store a heap of bulk grain. In using such a structure for the storage of grain it is envisaged that once filled with grain the fans blowing air into it could be switched off and the fabric allowed to collapse onto the bulk, when unloading is necessary the building can again be inflated. With such a building fitted with an integral floor the grain could be fumigated and reinfestation prevented by the continuous covering of the building. Tests on such a structure for the storage of bulk grain are currently being carried out at the instigation of the Pest Infestation Laboratory, Slough, England and work is also being carried out in Russia (6) and Germany (7). In Russia, for example, an airhouse holding

(4) Theimer, O.F., On the storage of raw cocoa beans in silo compartments, 1st Choc. Rev. 13, 122-126 & 162-167 (1958).

(5) Wright, P.N. and Southgate, B.J. The potential uses of plastics for storage with particular reference to rural Africa, Trop. Sci. 4, 74 - 81 (1962).

(6) Orlsen, B., Kulakovsky, A. and Prostoserdov, A., (Grain warehouses of air supported construction). Mukomol. Elevat. Promyah. 27, 14 - 16 (1961).

(7) Otto, F., Pneumatische Konstruktionen. Bauwelt, Berlin, 52, 571 - 576, (1961).

4000 tons of grain has been built and experiments are being carried out on structures supported by pneumatic arches. The use of such plastic buildings would add flexibility to existing storage systems.

21. Bulk storage at depots in overseas countries has been largely confined to the cereal grains. This is understandable since the amounts of these that are stored are far greater than for any other commodity. A most pertinent factor which influences whether or not a commodity shall be stored in bulk is that of transportation. The grain trade is so vast that special grain ships are available which can carry 10,000 tons of bulk grain. However there are few other commodities which could be shipped in similar quantities; although one hold in a ship may be devoted to carrying a commodity in bulk it is not very practicable to subdivide holds for commodities whose quantities are likely to vary on each shipment.

22. To meet these special conditions it should be possible to transport these commodities in semi-bulk containers which would be of such a size as to be lifted by a crane and of dimensions suitable for packing into holds of ships; thus, the weight of a filled container might be of the order of 15 tons. The most obvious advantage of such containers is the time saved in loading and unloading ships, thus ensuring quicker turn-round and a reduction in demurage costs and, the saving of the costs of the labour which would otherwise be used.

23. But there are greater benefits to be considered. The jute sack, commonly used at present for many commodities, is a most inefficient container in that insects have ready access to the commodity through the meshes of the sack fabric and unless an insect-proof barrier is added to or incorporated in the sack, commodities can never be maintained free of insects. An insect-proof container would thus be advantageous. In addition to this, if the container were insulated, trouble from water movement within a hold and subsequent condensation would be minimised. If the container were also gastight, its contents could be fumigated prior to shipping and they would be free of live insects on arrival in the importing country. It might also be possible to make these containers sufficiently airtight for them to act as hermetic containers.

24. It is a short step from this conception to realise that the use of bulk containers, apart from the immediate advantages at ports, could well be extended to the producing areas away from the ports. Crops, after harvesting and drying, would be put into these containers, fumigated to kill any stored products insects and thus would store without deterioration. Since these containers would be waterproof they could be stacked in the open, thus eliminating the need for storage premises.

Control of insect pests

25. In hot climates, in particular, certain species of insects infest the growing crop and at harvest are brought with it into store, where they continue their development. More usually stored produce becomes infested by insects occurring in the structure of a store, in residues of old crops, from other infested commodities stored nearby, or from the use of infested sacks during transport. Storage places should therefore be thoroughly cleaned before intake and any insects present in a commodity should be eliminated at the beginning of the storage period. The usual method of dealing with insect infestation is to treat the commodity with chemicals; this may be done with fumigants or contact insecticides. Alternatively, airtight storage may be used.

Chemical treatments

26. Fumigation involves treatment of the commodity with a gas which is toxic to insects. The choice of fumigant which can be successfully used for disinfestation of commodities in bulk is limited by the difficulties of achieving a satisfactory distribution of the gas through the bulk.

27. Certain liquid fumigants, notably mixtures of ethylene dichloride and carbon tetrachloride can be added continuously or intermittently to a stream of grain entering a bin and in certain circumstances they can also be used successfully in a surface application to the filled bins or to bulks on the floor of a closed store.

28. Phosphine, released from specially formulated tablets containing aluminium phosphide, is also widely used as a fumigant for bulk grain. The tablets must be evenly distributed through the grain either by addition to a stream or by introduction through hollow probes.

29. Methyl bromide, which is widely used as a fumigant for bagged or packaged commodities is difficult to apply successfully to large deep bulks unless there is provision for mechhanical circulation of the gas through the grain. However, it has been used for shallow bulks e.g. in floor heaps under sheets by vapourisation above the surface without circulation.

30. Effective fumigation, while killing all insects present in the grain, offers no protection against re-infestation and it is essential that precautions be taken to avoid new infestations. Methods of achieving this in bins are the use of insect-proof manholes or the application of a contact insecticide to the top layer of grain.

31. The alternative to fumigation is the use of contact insecticides. In large storage installations this may be done by mixing a very dilute insecticidal dust, e.g. malathion or lindane, with the grain as it enters the bins. Another technique using these dusts is a "sandwich" treatment where the insecticide is applied at suitably spaced intervals to layers of grain in bins. Recently, techniques of spraying grain with liquid applications of such insecticides as synergised pyrethrins and malathion have been developed; the advantage of the spraying methods is that there is no problem from air-borne dust. Treatments with contact insecticides to be effective should either kill the existing infestation, or at least stop breeding of the insect pests and provide for the further protection of the grain from reinfestation during its subsequent storage.

Airtight storage

32. Since insects require oxygen for their respiration they will die if deprived of air. Advantage of this fact is taken in airtight storage (8) where infested dry grain is stored in an airtight container - the insects consume the oxygen within the container and die from lack of oxygen. The heavier the infestation the quicker will the insects be killed; in very lightly infested grain the insects will breed but the second generation will be large enough to deplete the oxygen. Damage due to microorganisms which require oxygen can

(8) Agricultural Research Council. The airtight storage of grain, Annu. Rep. Agric. Res. Coun. 1959 - 60, (1961).

can also be prevented by this method of storage; it should be noted that in grain of high moisture content adverse changes take place which do not occur in grain of low moisture content stored in an airtight container. A container for airtight storage must initially be filled to capacity to keep the free space to a minimum.

33. A common design for an airtight storage structure is an underground or semi-underground pit. In the Argentine (9) for example, concrete pits up to 150 ft long, 40 ft wide and 20 ft deep are used. The walls extend slightly above ground level and were originally roofed with bitumen-felt bonded to the walls; permanent concrete roofs are now fitted. Pits of similar design have been used with success in Tanganyika (10) for the storage of a famine reserve of maize. An experimental pit at the Pest Infestation Laboratory, Slough (11) has given excellent results with maize stored for five years.

34. In Cyprus airtight bins are being used with success (12). These consist of cone-shaped concrete pits, about 30 ft deep with a domed roof. The dome is formed by applying mortar to sacking which in the constructional phase is supported by a timber framework. The pit and roof incorporate an efficient waterproofing layer.

35. When considering bins for developing countries, cost is of prime importance. A relatively cheap airtight bin can be constructed on a suitable circular waterproofed foundation as follows; a cylinder of spot-welded steel mesh is stood on the base and hessian tied to the inside, the cylinder is then filled with grain. The outside of the structure is then plastered with cement mortar. The roof is constructed by applying cement mortar to hessian temporarily supported on a timber framework; entry is by a suitably gasketed manhole at the apex of the bin. The bin is rendered waterproof by coating with bitumen.

36. Some experimental work has been carried out at the Pest Infestation Laboratory on airtight containers constructed from plastic materials. One of these was a bin whose walls were constructed of panels of glass-fibre/polyester resin, the top and bottom being sheets of a flexible plastic, neoprene-on-nylon. In this bin was stored wheat which was artificially infested with insects at the time of loading; this infestation died out in three weeks as a result of the hermetic conditions in the bin, and the wheat

(9) Argentine Ministry of National Economy. Storage of wheat in underground silos, Proc. U.N. Sci. Conf. Conserv. & Utilization of Resources, Lake Success, 1949, 6, 356 - 358 (1951).

(10) Swaine, G., Underground storage of maize in Tanganyika. East Afr. agric. J., 20, 122 - 128 (1954).

(11) Hyde, M.B., et al., Underground storage of grain, Pest Infest. Res. 1960, (1961).

(12) Oxley, T.A., et al., The new grain bins in Cyprus, Colonial Office, London (1960).

was then satisfactorily stored for a year (13). Another container took the form of a pillow which was constructed of a coated material, PVC-on-nylon in which maize was satisfactorily stored for ten months (14). These containers are shortly to be tested in the tropics. The materials used to construct such containers are at the moment somewhat costly and the possibility of using cheaper materials is being investigated.

37. With airtight storage no chemicals are required for the control of insects, an important factor when one has to bear in mind that tainting and contamination must be avoided. The chemicals used for the control of insects are toxic to man in varying degrees and recommendations for their safe use by operators must be observed. In many developing countries the use of chemicals may be limited, apart from costs, by the low educational standards which exist; in these circumstances airtight storage is a safe form of storage which could perhaps be practised more widely.

(13) Burrell, N.J. et al., Tests with a glass-fibre bin, Pest Infest. Res., 1961 (1962).

(14) Burrell, N.J. and Ashwell, F.J.E. Tests on a flexible plastic tank, Pest Infest. Res. 1961 (1962).

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